Streamflow Duration and Recreational Flows on Three Southeastern Streams

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Whitewater boating has become an important part of the economy and has significantly changed the cultural landscape of numerous communities in the Southeast. In this paper I examine the flow duration statistics for three Southeastern streams to determine how often they typically flow at rates sufficient for kayaking and rafting. Those three streams are shown to have substantial differences in the frequency with which flows are adequately sustained for whitewater boating; the Nolichucky averages over 300 opportunity days per year, while the Watauga and Emory average fewer than 100 opportunity days per year. Reasons for those differences are examined and related to a combination of climatic and geomorphic factors. Decadal and inter-annual variability of flows for the three streams are examined and temporal trends discussed.

Introduction

Whitewater boating has become an important part of the economy and has significantly changed the cultural landscape of numerous communities in the southeastern United States (Mayfield and DeHart 1989; Pyle 2000). The Nantahala River of western North Carolina records over 200,000 whitewater user days per year, generating over $14 million for the economy of Swain County (American Whitewater 2006a). American Whitewater negotiated recreational releases for the Cheoah River of Graham County that began in 2005. With at least 16 days of annual releases per year, the impact on the local economy is expected to start at $3.0 million per year (American Whitewater 2006a). Many of the rivers that are heavily used for whitewater recreation in the Southeast are dammed and thus subject to flow regulation. Flow regulation serves to provide reliable streamflow levels for boating that are often scheduled months in advance of release dates. The Nantahala and Cheoah Rivers are examples; recreational release schedules are published up to a year in advance for the Cheoah (American Whitewater 2006b). Regulated flow regimes therefore make recreational boating easy to schedule and also have important impacts on fluvial dynamics and the structure of rapids (Graf 1980; Mills 1990).

The whitewater section of the Cheoah River is entirely bypassed by a penstock that kept the riverbed dry for some seventy years until a river advocacy group negotiated with the dam operator for recreational releases as part of dam re-licensing (American Whitewater 2006b). Due to the agreement, the river flows for just sixteen days per year but those days are known well in advance and boaters from across the eastern United States plan trips to the Cheoah for the release dates. Conversely, the Nantahala release schedule is not determined in advance, but it is quite reliable. The commonly paddled section of the Nantahala is below the hydroelectric power plant, so whitewater recreation is possible whenever power is being generated, which occurs nearly every day of the year except during November, when dam maintenance occurs (American Whitewater 2007).

This paper focuses on three free flowing whitewater rivers in the Southeast, the Nolichucky (NC and TN), Obed-Emory (TN), and Watauga (NC and TN) (Figure 1). These streams are essentially free of impoundments; their flow regimes are based entirely on local climatological conditions rather than being determined by electrical demand schedules or transportation flow requirements. While many paddlers express a preference for free flowing streams (Abbey 1982; Woodward 2006), the variability of natural streamflow often makes it impossible to plan a kayaking or rafting excursion even a day in advance. In this paper I examine the flow duration statistics of three Southeastern whitewater streams in comparison to minimum flow requirements for boating.

The Study Streams

The Nolichucky River drains a watershed of 805 mi.^{2} above the gage at Embreeville, TN (gage 03465500, USGS 2007a). The stream originates on the flanks of Mt. Mitchell, the highest peak east of the Mississippi. The river has Class III-IV rapids and is regularly used for commercial rafting during the late spring and summer months (Benner and Benner 2006). The Obed-Emory River drains a watershed of similar size (764 mi.^{2} at USGS gage 0340500) on the Cumberland Plateau of Tennessee (USGS 2007b). The Emory watershed contains a wide variety of boatable river reaches, from Class I to Class V (Sehlinger and Lantz 1979). Flow statistics cited here refer to flows on the Class II-IV lower Obed section of the watershed. The Watauga is by far the smallest of the three watersheds, with a drainage basin encompassing only 92 mi.^{2} (gage 03479000, USGS 2007c). Rapids within the gorge section of the Watuaga are rated as Class IV-V (Benner and Benner 2006). The Watauga Gorge is not regularly used for commercial rafting, due at least in part to the challenging nature of the rapids and presumably, the unreliable nature of its flow regime. Opportunistic kayakers are known to drive from as far away as Florida and Colorado to attempt its rapids when flows are appropriate.

The three watersheds are all within a three hour drive of Knoxville, Asheville, and Johnson City. Atlanta, Raleigh, and Charlotte are within a six hour drive of each of these rivers and most of the eastern seaboard is within a one-day drive of each. Kayakers typically decide where to travel for a weekend of paddling by checking current flow levels online. Those who go rafting with commercial outfitters more commonly choose a destination and a time well in advance as part of a planned vacation.

Flow Regimes

The interaction between channel materials and shear stress generated by peak flows is generally responsible for river channel configuration. River channel configurations that confine flow to a single thread are more likely to result in the ability of whitewater craft to descend a reach at low flows than if multiple threads are common. The rapids of these three streams result from a combination of bedrock ledges, boulder deposits, and large blocks delivered to the stream channel directly from adjacent cliffs. Personal observation of those rapids on the three streams for the last thirty years has shown them to be exceedingly stable even in the presence of large floods (RI>25 years). Examination of air photos dating to 1950 and dendrochronological analysis of the mid-channel deposits of the Obed revealed that those features are only minimally affected by floods with recurrence intervals greater than 25 years (Mayfield 1989).

What is the minimum level of flow at which a specific reach of a river can be floated by kayakers or rafters? Unfortunately, any answer to that question is somewhat arbitrary and largely individual. The answer depends in part on the type craft being used to navigate the river. A skilled kayaker paddling a modern whitewater kayak can generally navigate a

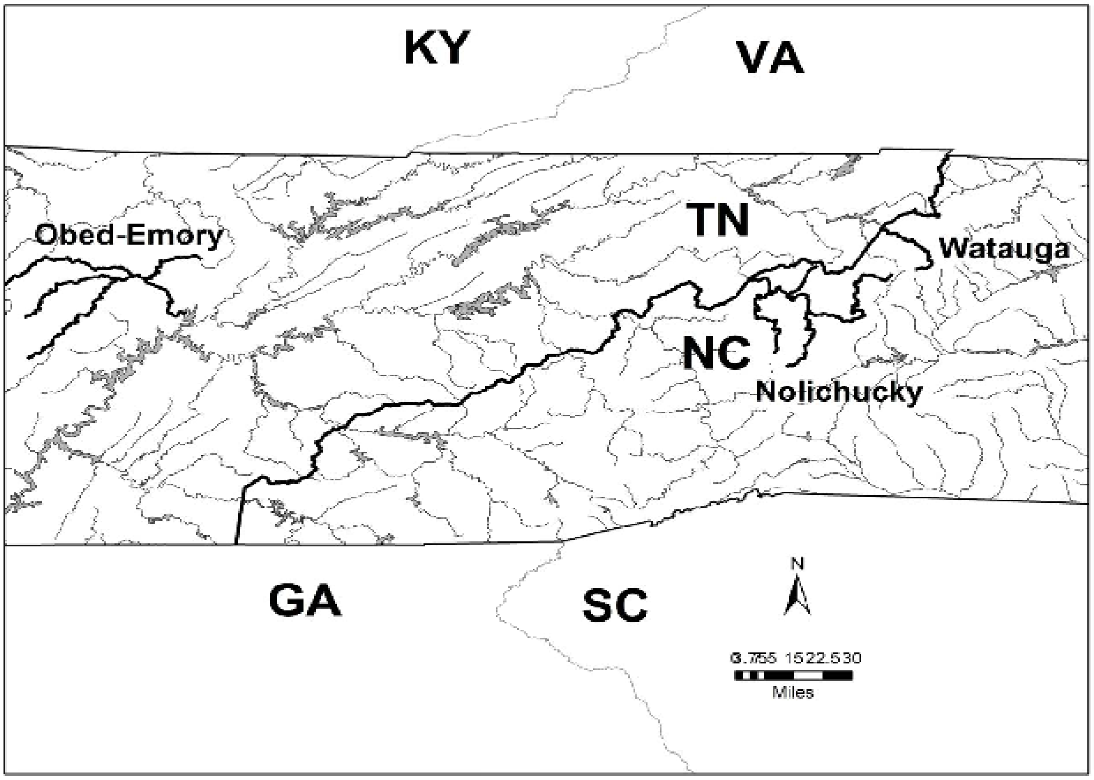

Figure 1. The Study Streams.

whitewater river at levels lower than can be achieved by a whitewater canoe or raft. Ultimately it becomes a matter of preference; while one guidebook recommends a minimum flow of 125 cfs for paddling the Watauga Gorge, very few boaters choose to do so (Benner and Benner 2006). A more practical minimum flow is 200 cfs, as expressed by numerous members of the local paddling community (Lambla 2007; Simpson 2007). Figure 2 shows the Watauga River at the minimal acceptable flow of 200 cfs. Fortunately, there are broadly accepted minimum flows that are developed by consensus within the whitewater community. Those recommended minimum flows are recorded in guide books as well as widely used web sites. The minimum flows used for this analysis are contained in Table 1.

While published minimum flows are generally accepted by large numbers of paddlers, maximum flows are much more likely to engender debate and controversy. Minimum flow for boating is largely a function of river channel morphology relative to streamflow, while maximum acceptable flows are much more a function of boater skill, boat technology, and machismo. Skilled kayakers regularly paddle rivers at discharges that are several times greater than the recommended cutoff levels reported in guidebooks. Therefore I will limit discussion to minimum flows in this paper.

Mean daily streamflow values were downloaded from the USGS National Water Information System and processed to determine flow duration statistics (USGS 2007a, b, c). The period of study was 9/1/1940 through 12/31/2006, which is the common period of record for the three stream gages. The mean daily discharge is probably the best criterion available to determine flow duration statistics

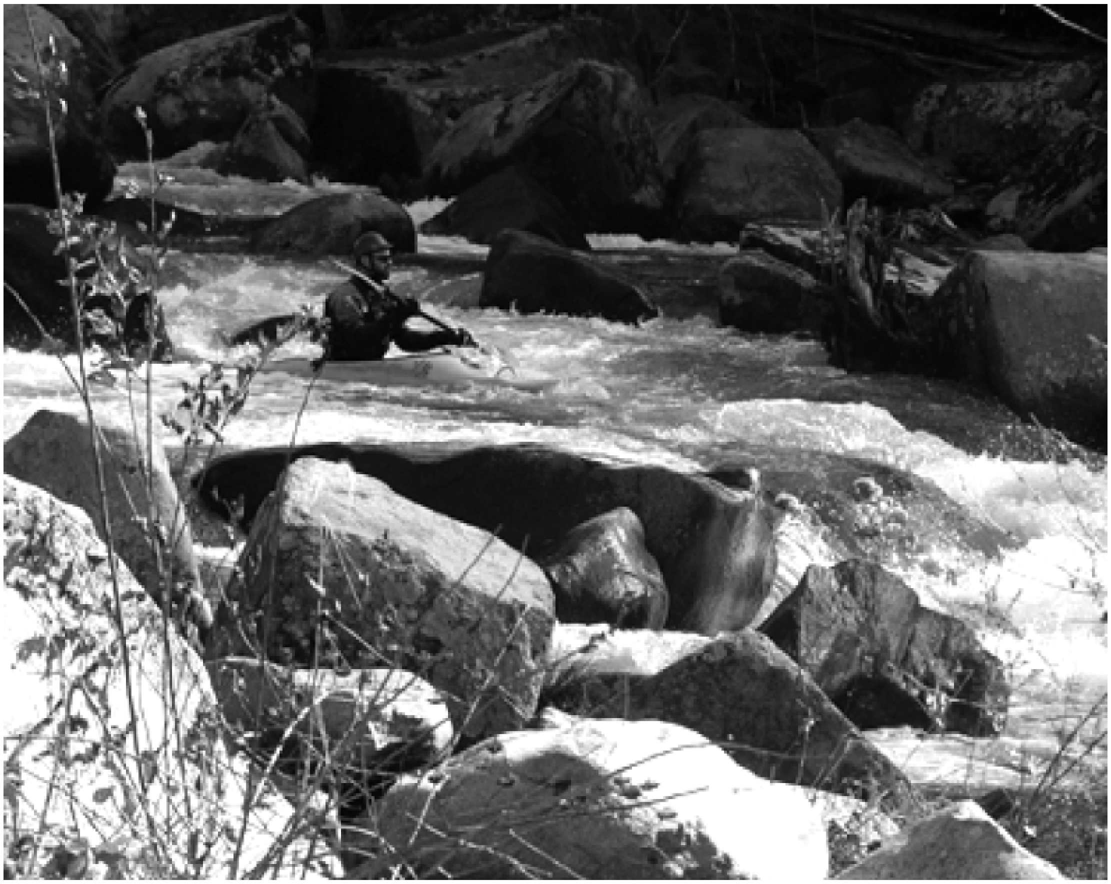

Figure 2: The Watauga River at the minimum flow of 200 cfs. Photo by the author.

Table 1. Critical kayaking and rafting flows used in this study.

River	***Minimum flow (cfs)***	***Source***
Obed-Emory	1500	Sehlinger and Lantz 1979
Nolichucky	500	Benner and Benner 2006
Watauga	200	Consensus of local boating community

for the historical period but it is not without problems. For example, it is possible for the mean daily discharge to be somewhat below the accepted minimum threshold value, but for the river to flow at an adequate level for part of that day. If that acceptable flow occurs during daylight hours, it is possible for opportunistic boaters to "catch the bubble" and paddle the river. A good example is that on October 17, 2006 the Watauga River began the day flowing at a level well below 100 cfs (USGS 2007c). As rain fell throughout the day, the river level rose and exceeded the minimum flow level for several daylight hours (Figure 3). Even though the mean daily discharge of 170 cfs was below the 200 cfs threshold, it was indeed possible to paddle the Watauga in the late afternoon. A similar situation occurred on October 30 but with a much shorter window of opportunity. In both of those cases it would have been possible for a paddler living very close to the river to take advantage of the situation. However, it has been my experience that only a small number of kayakers living near Boone are able to take advantage of those opportunities because of the basin lag time, an average two hour delay in gage reports reaching Internet sites, and the driving time necessary to respond (Mayfield 2004). More importantly, most such situations occur in the summer with convective storms that occur in the mid- to late-afternoon. With a basin lag factor of approximately seven hours, the resulting high water reaches the threshold near midnight and subsides before the next morning. The Nolichucky and Obed rivers have much larger watersheds and considerably longer basin lag factors, so short duration events rarely result in boating opportunities.

Annual Streamflow Duration

An opportunity day is here defined as a day when the mean daily discharge of a river is above the minimum level recommended in published guidebooks. The only criterion considered is that of having adequate river discharge to float the designated section of the river. No attempt is made here to exclude days on the basis of excessively high water or adverse weather. The average number of annual opportunity days for each of the three study streams is presented in Table 2.

The Nolichucky River has such well-sustained flows that it can be paddled nearly every day of an average year. As indicated in Table 2, the Nolichucky flows above the recommended minimum level of 500 cfs for an average of 304 days per year. Low flow duration characteristics of rivers are widely reported to be proportional to watershed size (Black 1996; Weaver 2001). The Nolichucky drains one of the larger, wetter watersheds of the southern Appalachians. It is not especially surprising that such a large watershed yields substantial low flows and a long boating season. However, the Obed-Emory River drains a watershed that is essentially equal in size to that of the Nolichucky but it yields an average of only 99 paddling days per year. That watershed has been shown to have an exceptionally flashy flow regime, considering its climate and terrain characteristics (Mayfield 1979). The extreme variability of flow was attributed to a general dearth of soil and bedrock storage within the watershed, compared to other streams in the region (Mayfield 1986). As a result of this flow regime, the Emory and its tributaries support very little commercial rafting and are paddled primarily by boaters in east Tennessee. Of the three streams, the Watauga has the shortest season with only 89 opportunity days per year.

Monthly Flow Duration

Monthly patterns of flow duration are significant in that they can indicate seasonal patterns of opportunities. Figures 4-6 reveal those monthly mean flow patterns. The Nolichucky River's mean monthly flow for each month of the year is above the recommended minimum level of 500 cfs, reinforcing the observation that its flows are well sustained. It is rare to find flows below the critical value of 500 cfs at any time of the year, so boaters often use the Nolichucky as a fall-back location to paddle if steeper, flashier streams lack adequate flow. Watauga River and Emory River flows again fall far short of those of the Nolichucky by

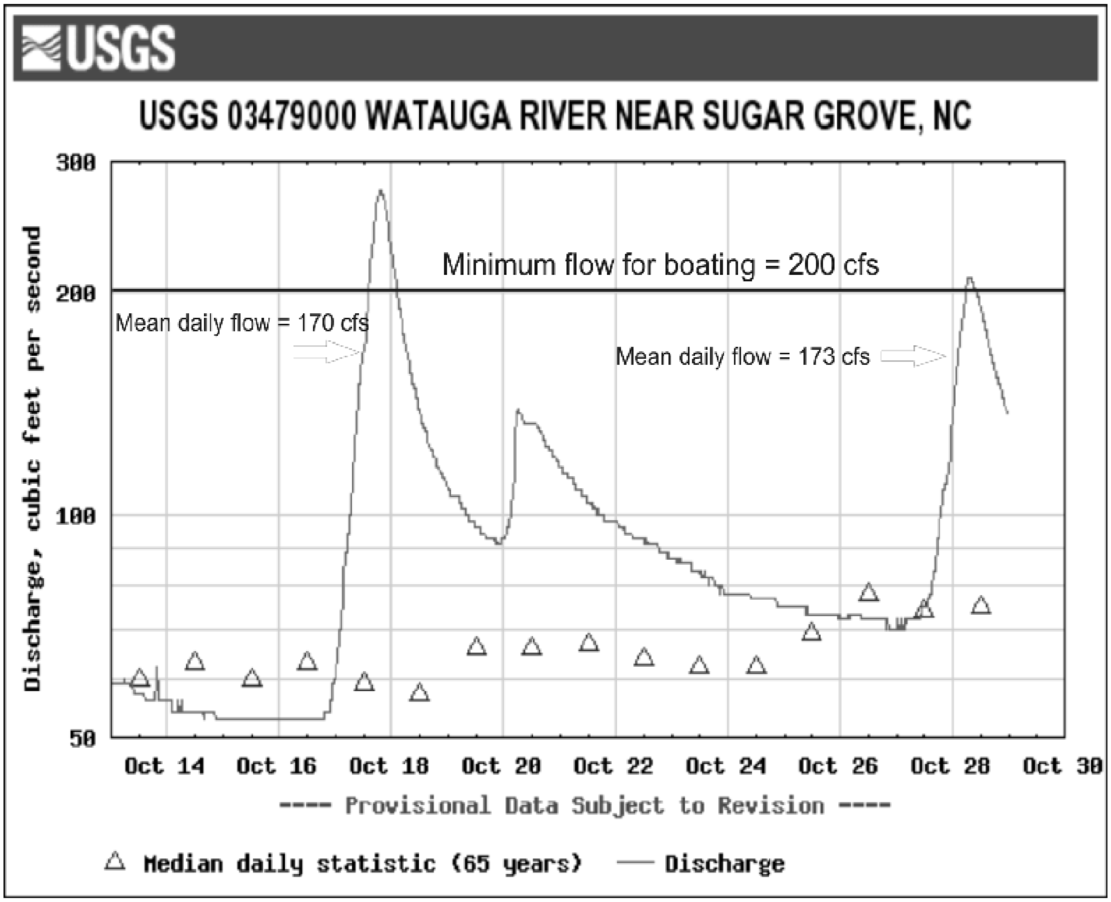

Figure 3: Discharge of the Watauga River, October 14-30 2006. Source: USGS 2007c.

Table 2. Average Number of Opportunity days per year on the three study rivers. Source: Calculated from USGS (2007a, b, c).

River	*Number of Days*	*Percent of Days*
Obed-Emory	99	27.07
Nolichucky	304	83.29
Watauga	89	24.46

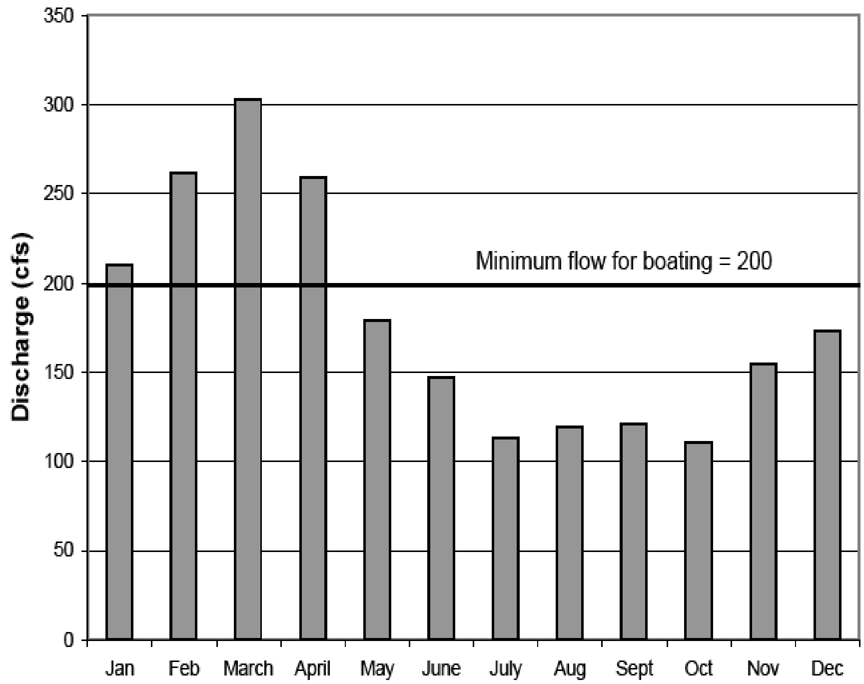

Figure 4: Mean monthly discharge of the Watauga River. Source: USGS 2007c.

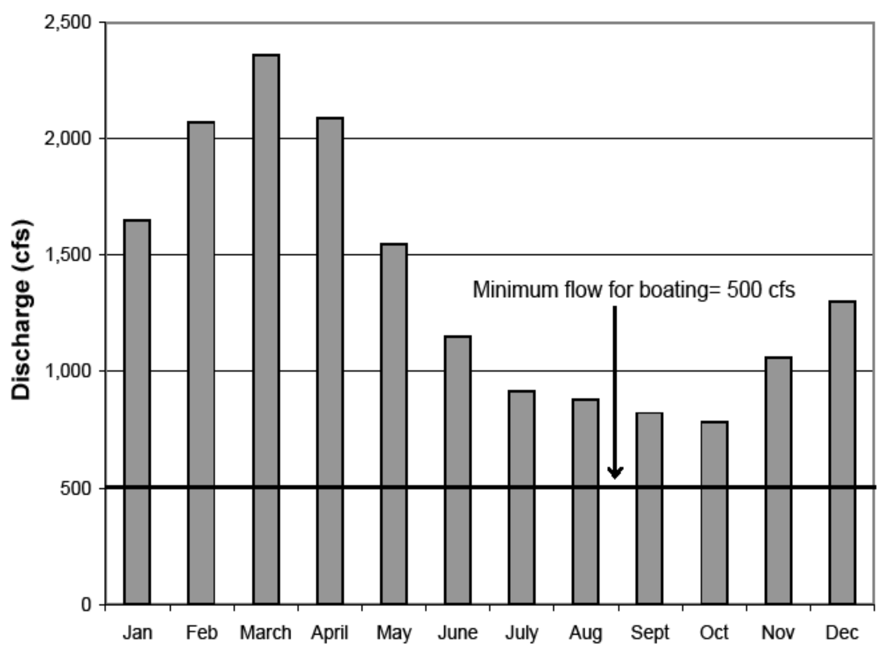

Figure 5: Mean monthly discharge of the Nolichucky River. Source: USGS 2007b.

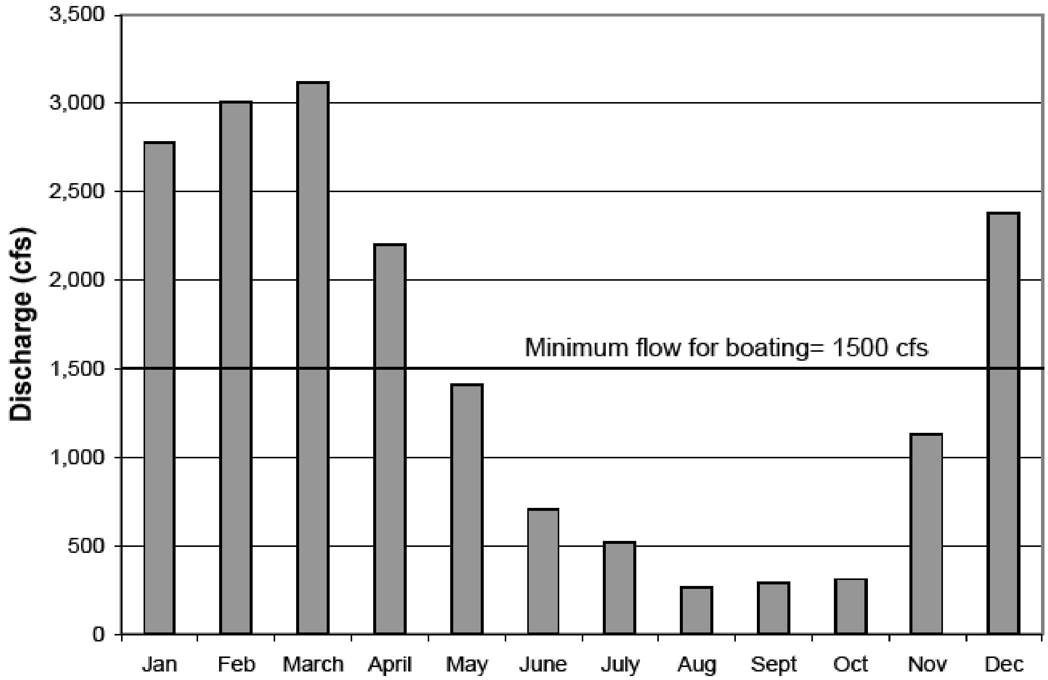

Figure 6: Mean monthly discharge of the Emory River. Source: USGS 2007a.

this measure. Mean monthly flows on the Emory are above the recommended minimum during only five months of the year; the Watauga River's mean monthly flows only exceed the minimum paddling level during four months of the year. All of those months are during the cold period of winter and early spring.

Opportunity days arise for the Watauga River throughout the year, even during the summer months when median monthly discharge values are at least 25% below the threshold for paddling. In this small watershed, a convective storm can yield enough runoff for the river to rise above the 200 cfs threshold. Conversely, the Emory River tends to flow at levels far below its threshold for the entire period of June through early November, with little chance of rising to its threshold value of 1500 cfs.

Inter-Annual Variability of Flows

Year-to-year variations in annual and seasonal precipitation in the Southern Appalachians and the Southeast in general have been attributed to a wide variety of atmospheric phenomena, including ENSO and the North Atlantic Oscillation (Henderson and Robinson 1994; Henderson and Vega 1996; NC SCO 2006; Zorn and Waylen 1997). Those variations can have substantial impacts on the number of opportunity days for a river such as the Watauga, as the river flows at levels very close to the threshold for paddling for much of the year. Figure 7 reveals that all three study streams have shown significant variations in the number of annual opportunity days over the last decade, but those variations have been greatest for the Watauga.

Annual precipitation and runoff has varied dramatically in the Watauga watershed during the last decade. Streamflow statistics for that period reveal that the mean annual flow varied from a low of 82 cfs in 1988 to a high of 273 in 1992. Other drought years such as the extended dry period from 1999

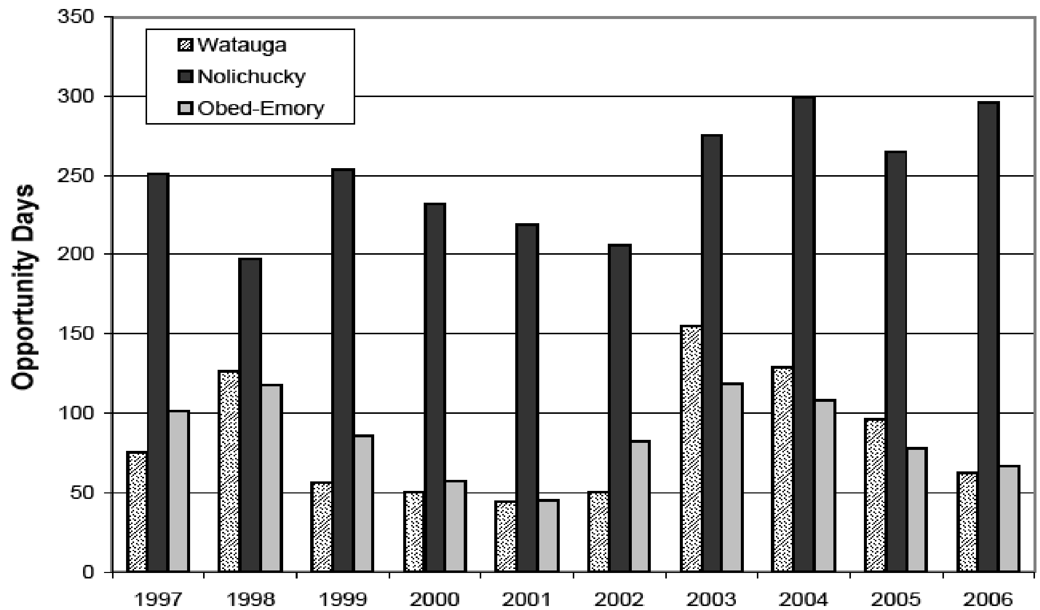

Figure 7: Annual kayak and raft paddling opportunity days. Source: Calculated from USGS 2007a,b,c.

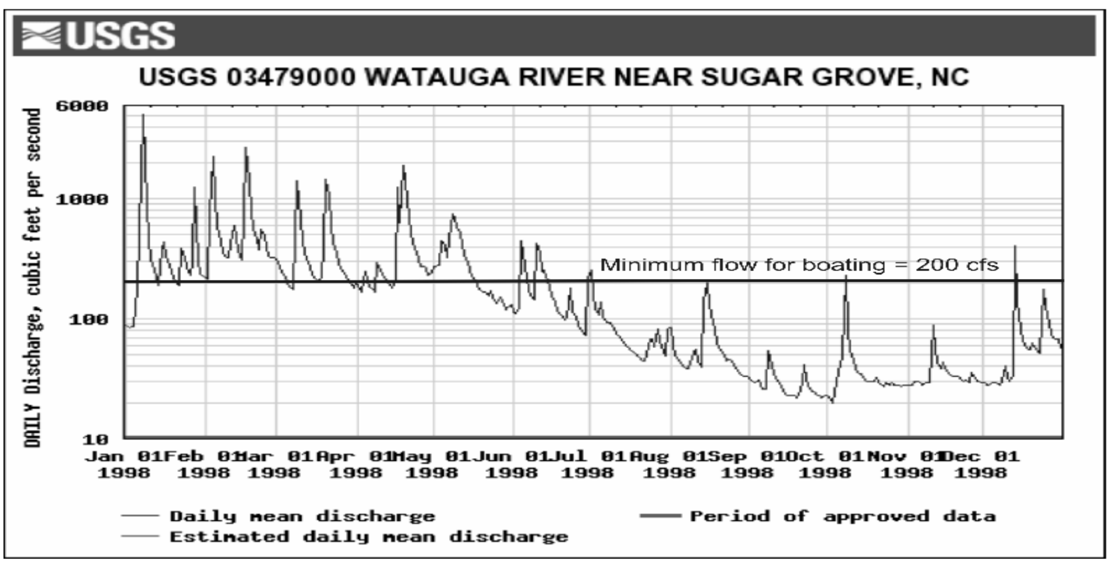

Figure 8: Mean Daily Discharge of the Watauga River, January 1-December 31, 1998. Source: USGS 2007c.

through 2002 were clearly associated with strong La Niña events, which have been found to be associated with prolonged drought in the Southeast in general and North Carolina in particular (NC SCO 2006; Robinson 2005). Significant flow variability is to be expected for a small mountain watershed. However, the fact that the median flow values for the Watauga are so close to the threshold for recreation use means that modest variations in flow can result in significant changes in the number of opportunity days.

The last decade has seen a substantial variation compared to the long-term (1940-2006) average of 24.46% of all days having more than the minimum flow. The period from 1999-2002 was clearly a tough time for kayakers in the North Carolina High Country and 2006 was almost as bad, although the onset of a moderate El Niño event coincided with a large number of opportunity days in late November and December.

Flow variability can be substantial even within a single calendar year. The strong El Niño event of the late 1990s ended abruptly with rapidly cooling tropical Pacific sea surface temperatures in June of that year (NOAA 2006). Substantial flow variability occurred during the 1998 calendar year, as there were 126 opportunity days on the Watauga prior to from January 1, 1998 until May 31, 1998 and only four opportunity days during the second half of the year (Figure 8). Future research will focus on an analysis of the relationships between the number of opportunity days for paddling on these streams and various climate indices, including NAO and ENSO.

Conclusions

Flow duration and reliability of flows are important variables when many paddlers decide where to go rafting or kayaking. The number of opportunity days to paddle a river each year is clearly an important variable in motivating boaters to select specific locations to paddle. Private investors recently built an artificial whitewater recreation center outside of Charlotte, with over $37 million in government guaranteed funds (Willoughby 2006; USNWC 2007). One of the announced purposes was to provide reliable flows on demand. As a result of those reliable flows, the facility was named the Olympic training center for whitewater canoeing and kayaking. Reliability of flow is of great importance for many whitewater paddlers, as noted for the Cheoah River.

Continued growth of the whitewater recreational industry is largely dependent upon precipitation patterns and resultant runoff rates that vary dramatically over even short periods of time in unregulated watersheds. On smaller rivers such as the Watauga and flashy rivers such as the Obed-Emory, those flows have been shown to be highly erratic. Numerical models have suggested that runoff in the Southeast is likely to decline in face of a warming climate during the 21st century (USGCRP 2006). The dry decade of the 1990s may prove to be a modest analog for leaner times to come for whitewater boaters if those model projections hold true.

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